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Over the past several years, the Principal Investigator has made significant contributions to the understanding of compressible turbulent flows. He has utilized innovative modern optical diagnostics to explore 1) the turbulence structure of wall bounded shear layers, 2) the effects of extra strain rates, such as convex curvature and favorable pressure gradient, on the turbulence structure of wall bounded shear layers, 3) the effect of compressibility on the Reynolds stresses and the turbulence structure of free shear layers, and 4) control of supersonic jets. The latest state-of-the-art optical diagnostics that the PI has been using include Filtered Rayleigh Scattering (FRS) technique for flow visualizations, and Planar Doppler Velocimetry (PDV) technique for instantaneous velocity measurements.

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ABSTRACT

Over the past several years, the Principal Investigator has made significant contributions to the understanding of compressible turbulent flows. He has utilized innovative modern optical diagnostics to explore 1) the turbulence structure of wall bounded shear layers, 2) the effects of extra strain rates, such as convex curvature and favorable pressure gradient, on the turbulence structure of wall bounded shear layers, 3) the effect of compressibility on the Reynolds stresses and the turbulence structure of free shear layers, and 4) control of supersonic jets. The latest state-of-the-art optical diagnostics that the PI has been using include Filtered Rayleigh Scattering (FRS) technique for flow visualizations, and Planar Doppler Velocimetry (PDV) technique for instantaneous velocity measurements. The PDV technique that has been under development in the PI's laboratory for the past several years, has recently received considerable attention. In the above mentioned techniques, one freezes the flow for several nanoseconds using a pulsed laser and acquires a planar image of the flowfield using an ICCD camera. An ensemble of such images is used to obtain qualitative and/or quantitative statistical information on the flowfield. Because of the very long time lapse between pulses, all the information on the evolution of and the interaction among structures in the flow is lost. With the advances in ultra fast ICCD cameras, one could obtain real-time images of high speed flows which possess both qualitative and quantitative information, if appropriate high power cw lasers or pulsed lasers were also available. Unfortunately, narrow linewidth cw lasers do not have enough power, and high power pulsed lasers with narrow linewidth do not have very high repetition rates. Therefore, under this grant we have purchased a framing streak camera (Hamamatsu C4187) with a framing rate up to 3,000,000 frames/s and an injection seeded double-pulse Nd:YAG laser (Continuum Powerlite 8010). The camera can provide only eight images at a time. Combining this laser with another similar laser that is available in the PI's laboratory, we can now obtain either two successive images of supersonic flows on two different planes simultaneously or up to four images of a given plane at a rate of 100,000 images/s. All the equipment are currently in place. We will shortly start real-time visualizations and measurements in supersonic flows. The acquisition of that this new system has substantially advanced our high speed flow diagnostics capabilities.

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INTRODUCTION

Many flight vehicles of interest to DoD are affected by compressible turbulent flows, e.g. I) compressible turbulent boundary layers over the wing of high speed aircraft that generate drag and instabilities, ii) compressible mixing layers in scramjet types of applications that are notorious for poor mixing with fuel, and iii) compressible jets where the jet noise and the infrared plume signature are produced. Our current understanding of these flows are marginal, at best. There is practically no reliable information on either the evolution of and the interaction among turbulence structures in these flows or on the spectral content of these structures. Needless to say that these structures are major contributors of drag on vehicles, entrainment and mixing in combustors, and sources of the jet noise in supersonic jets. Therefore, understanding of their nature, evolution, and interaction, and eventually improving our capabilities to predict and control these processes, is crucial to many DoD missions. Some information on these structures is currently obtained by techniques such as hot-wire which is an intrusive technique and is sensitive to all the fluctuating modes of turbulence. Some information is also obtained using double-pulse imaging, which provides little information on the evolution of and the interaction among turbulence structures. As will be discussed next, the equipment acquired under the AFOSR DURIP grant will enhance the Principal Investigator's capabilities to obtain detailed information on the structure of the above mentioned flows, and thus to improve our understanding of these flows.

Over the past several years, the Principal Investigator has made significant contributions to the understanding of compressible turbulent flows. He has utilized innovative modern optical diagnostics to explore 1) the turbulence structure of wall bounded shear layers, 2) the effects of extra strain rates, such as convex curvature and favorable pressure gradient, on the turbulence structure of wall bounded shear layers, 3) the effect of compressibility on Reynolds stresses and the turbulence structure of free shear layers, and 4) control of supersonic jets, . The latest state-of-the-art optical techniques that the PI has been using include Filtered Rayleigh Scattering (FRS) techniques for flow visualizations, and Planar Doppler Velocimetry (PDV) technique for instantaneous velocity measurements. The PDV technique that has been under development in the PI's laboratory for the past several years, has recently received considerable attention. In the

above mentioned techniques, one freezes the flow for several nanoseconds using a pulsed laser and acquires a planar image of the flowfield using an ICCD camera. An ensemble of such images is used to obtain qualitative and/or quantitative statistical information on the flowfield. Because of the very long time lapse between pulses, all the information on the evolution of and the interaction among structures in the flow is lost.

With the advances in ultra fast ICCD cameras, one could obtain real-time images of high speed flows which possess both qualitative and quantitative information, if appropriate high power cw lasers or pulsed lasers were also available. Unfortunately, narrow linewidth cw lasers do not have enough power, and high power pulsed lasers with narrow linewidth do not have very high repetition rates. Therefore, under this grant we have purchased a framing streak camera (Hamamatsu C4187) with a framing rate up to 3,000,000 frames/s and an injection seeded Nd:YAG laser (Continuum Powerlite 8010). The camera can provide eight images at a time. Combining this laser with another similar laser that is available in the PI's laboratory, we can now obtain either two successive images of supersonic flows on two different planes simultaneously, or up to four images of a given plane at a rate of 100,000 frames/s. All the equipment are currently in place. We will shortly start real-time visualizations and measurements in supersonic flows. Needless to say that this new system has substantially advanced our high speed flow diagnostics capabilities.

CURRENT STATUS

We spent a considerable amount of time and effort to locate a high dynamic range, high frame rate intensified CCD camera that can detect single photon type low level signal. After locating the camera, we convinced the company to bring the camera to our laboratory so we could directly evaluate its performance in the type of environment that we would be using the camera. The camera is a framing streak camera from Hamamatsu, Model C4187, with excellent specifications and performance. It is a complete system with all the necessary hardware and software. It is a 12-bit camera (4096 grey scales) that can detect a single photon. The camera can take anywhere from 1 to 8 successive images with framing rate from 100 to 3,000,000 frames/s and exposure time for each image from 50 ns to 1 ms. The repetition rate for an ensemble of 8 images is 100 Hz. This is the best camera of its class. Since it is a very unique camera, its delivery took a long time (about 8 months). We received and evaluated it through a rigorous set of tests. The experiments are under way to use this camera in supersonic flows.

We had much harder time to locate an appropriate laser. The ideal laser would be a narrow linewidth high power pulse-burst laser with a string of eight pulses. Such a laser then could be used with the camera discussed above to obtain qualitative and quantitative images of supersonic flows on a given plane. This would provide real-time information on the structure of supersonic flows. First, there is no such a laser in the market. In fact, the technology is not there yet to design such a laser. It can be done if one can overlook the narrow linewidth aspect of it. If one does this, then one cannot obtain quantitative images. Second, one cannot get simultaneous images in more than one plane with such a camera. As a result, we decided to acquire a high power, narrow linewidth, double-pulse laser from Continuum (Powerlite 8010). Combining this laser with a very similar laser in the PI's laboratory, we can obtain two types of images in high speed flows. First, we can get simultaneous images of two different planes in a supersonic flow. In fact, we could get two successive sets (75 kHz rate) of simultaneous images. Second, we could obtain four successive images (100 kHz rate) on a given plane. Obviously, these images will provide enormous information on three-dimensional flows and the evolution of structures in these flow.

We have received, set up, and tested both the camera and the laser. We just finished setting up the combined system of the camera and two lasers. We are planning to use the system in high speed flows in about two weeks. Within a few months we will have preliminary real-time visualizations in high speed flows.